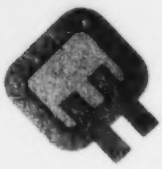

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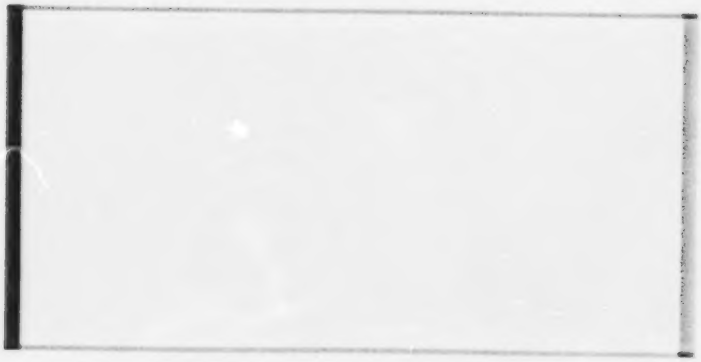

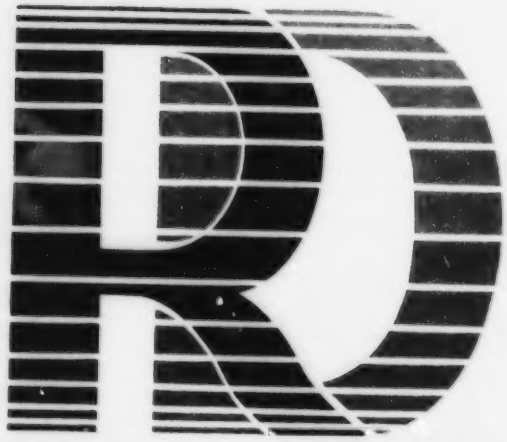

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FEASIBILITY OF A TRACER GAS TECHNIQUE FOR CONTAINMENT LEAKAGE CHARACTERIZATION AT BRUCE NGS

V.P. Singh
Environmental & Inorganic
Research Section
Chemical Research Department
Report No 85-239-K

ABSTRACT

Methods for tracer gas tests have been conceived and are proposed for use in conjunction with other techniques used during off-power pressurization tests. During pressurization tests it appears possible to quantify leaks through containment boundaries which make up one of the walls in adjacent rooms but quantification of leaks to open areas will require further development. Several gases may be used as tracers during pressurization tests but the preferred tracer gas is sulphur hexafluoride (SF_6) at an in-vault concentration of 100 µL/L if open area sampling is to be carried out or 10 µL/L if only closed room sampling is to be performed. Large values of the ratio (tracer gas concentration in containment/lower detection limit) are necessary for identification of leak sites in open areas having significant ventilation flow. It is recommended that in-station trials be carried out to test the validity of this technique.

In addition, a tracer gas technique for use during on-power operation is also proposed but leak site identification and quantification during on-power tests is only possible for containment boundaries which make up the wall(s) of adjacent rooms. The use of SF_6 is required for tests conducted during on-power operation. The recommended in-vault concentration is 10 µL/L. Recommendations are made for future work, including leak tests during on-power operation.

job	file	date	report no.
740631-270-450	835.6212	November 1, 1985	85-239-K

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EXECUTIVE SUMMARY

FEASIBILITY OF A TRACER GAS TECHNIQUE FOR CONTAINMENT LEAKAGE CHARACTERIZATION AT BRUCE NGS

V.P. Singh
Environmental and Inorganic Research Section
Chemical Research Department

Penetrations through concrete, joints in concrete, and cracks in concrete are reported to be major sources of containment leakage in nuclear generating stations. For Bruce NGS "A", the leakage specification is 1% of containment volume per hour (16000 L/min) at the design pressure of 69 kPa(g). At 69 kPa(g) this flow rate may be obtained through a single slit of width 0.3 mm and total length of only 4 metres but will most likely be due to many leak sites. Current techniques for leak site identification and leak quantification in nuclear generating stations have accounted for only a small fraction of the total leak rate. A research program partially supported by CANDEV funds has been undertaken by the Chemical Research Department on the methodology for leak site identification and leak quantification. The work concentrated on Bruce NGS "A" because an off-power leak test will be carried out there in 1987.

Methods for tracer gas tests have been conceived and are proposed for use in conjunction with other techniques used during off-power pressurization tests. During pressurization tests it appears possible to quantify leaks through containment boundaries which make up one of the walls in adjacent rooms but quantification of leaks to open areas will require further development.

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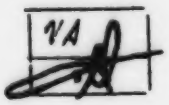
In addition, a tracer gas technique for use during on-power operation is also proposed but leak site identification and quantification during on-power tests is only possible for containment boundaries which make up the wall(s) of adjacent rooms. Of the gases studied, SF_6 only is suitable for tests conducted during on-power operation. The recommended in-vault concentration is 10 µL/L. Recommendations are made for future work, including leak tests during on-power operation.



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To Mr. D.W. Souther
Manager - Nuclear Systems

FEASIBILITY OF A TRACER GAS TECHNIQUE FOR
CONTAINMENT LEAKAGE CHARACTERIZATION AT BRUCE NGS

1.0 INTRODUCTION

Penetrations through concrete, joints in concrete, and cracks in concrete are reported to be major sources of containment leakage in nuclear generating stations/1/. For Bruce NGS "A", the leakage specification is 1% of containment volume per hour (16000 L/min) at the design pressure of 69 kPa(g). At 69 kPa(g) this flow rate may be obtained through a single slit of width 0.3 mm and total length of only 4 metres but will most likely be due to many leak sites/2/. At Bruce NGS "A", steel lining is used throughout containment except for the ceiling and upper two-thirds of the walls of the fuelling machine duct under the reactor auxiliary bay. These areas have an epoxy coating as does Pickering NGS "A". The potential for leaks through cracks and joints in the concrete in these areas may be greater than through the steel lined areas.

Presently, the overall leak rate is determined by pressurizing all or a portion of containment at one or more pressure levels above atmospheric. A measurement is made of the flow of instrument air required to maintain each pressure level, or of the rate of fall of pressure. Corrections for temperature and humidity changes, etc, are applied. The parts of the containment envelope normally tested simultaneously are the four reactor vaults, the fuelling machine duct, the pressure relief duct and manifold at the vacuum building, and the central fuelling area. These are all connected to each other. The vacuum building is normally tested separately.

Techniques employed for leak site identification include the use of Leak-Tec (soap solution) and an ultrasonic method developed by the Chemical Research Department/3/. Use of these techniques has resulted in only a small fraction of the total leak being accounted for at present. This may be due to the large area to be searched and the localized nature of the above techniques. There are other disadvantages, also. Soap bubbles, while very efficient for identifying small leak sites (<1 L/min through holes less than about 1 mm diameter) give the false impression that the leak is very large. For larger leaks, the solution is rapidly blown away and no bubbles are formed. Also, use on the underside of surfaces is difficult. Similarly, for leaks (>approx 40 L/min) through holes typically 2 to 5 mm diameter, the ultrasonic method appears to be of limited accuracy. A tracer gas technique appears to have potential in complementing the above techniques through identification of those sectors which have significant leakage. Such sectors could include an entire unit or portions of a unit, eg, the north passages and the reactor reactivity controls area. Directional indication of leak origin may also be possible together with quantification of leaks greater than 20 to 40 L/min.

A research program partially supported by CANDEV funds has been undertaken by the Chemical Research Department on the methodology for leak site identification in the containment envelope of nuclear power plants/3/. As part of this program this study was undertaken to examine the feasibility of the tracer gas technique for containment leak identification and leak quantification. The work concentrated on Bruce NGS "A" because an off-power leak test will be carried out there in 1987.

2.0 METHODOLOGY

The development of a procedure for leak site characterization by tracer gas requires consideration of several factors:

(a) availability of injection and sampling lines;

(b) compatibility of proposed tests with tests presently used;

(c) mixing of the tracer gas within containment;

(d) nature of areas outside containment adjacent to penetrations;

(e) ability to isolate process equipment;

(f) choice of tracer gas.

These have been summarized in Table 1. From consideration of these factors it would appear that it is possible to carry out tracer gas studies in conjunction with other techniques used during off-power pressurization tests. It is also possible to carry out a limited tracer gas test during on-power operations.

2.1 Tracer Studies During Presently Used Pressurization Tests

2.1.1 Pressurization Tests - Tracer Injection

As discussed in Appendix B, tracer gas will be injected at several locations near the end of the pressurization period but prior to fan shutdown. If the pressure exceeds 115 kPa (2 psig), the vault cooling fans may have to be shut down or run intermittently so as not to overload the motors. Mixing in the vault area will be excellent except at higher pressures when only intermittent fan operation may be possible. Installation of fans on the fuelling machine trolleys to mix the air in the fuelling machine duct, the pressure relief duct, the central fuelling area, and other locations, eg, the east service area of Bruce "B" will be necessary for more accurate results.

Factors influencing the choice of a tracer gas are discussed in Appendix A. The preferred tracer gas is sulphur hexafluoride at in-vault concentrations of about 100 μL/L if open area sampling is to be carried out or 10 μL/L if only closed room sampling is to be performed. It will be necessary to intermittently sample the gas in each vault area. This will reduce uncertainties due to poor mixing in the fuelling machine ducts, sorption of the tracer gas on concrete or epoxy paint in the unlined areas and diffusion of the tracer gas through the concrete or epoxy paint. Disadvantages of SF_6 include breakdown at high temperature to form corrosive products. These may accumulate in the D_2O recovery dryers. However, although the effect is estimated to be small it requires further investigation.

TABLE 1

FACTORS AFFECTING DEVELOPMENT OF TRACER GAS LEAK SITE CHARACTERIZATION PROCEDURE

Factors Including Station Constraints	Relevance
(a) Injection/sampling lines availability	
- instrument air system	Tracer injection possible with pressurizing air. Tracer make up not required to compensate for instrument air in-leakage. Measurement of latter required.
- tritium sampling lines (or other lines) for tracer gas sampling	Tracer concentration in vault determinable. Valves on tritium lines are manually operated within the vault, therefore it will be necessary to open valves before tracer gas testing begins. Many rooms adjacent to containment have tritium sampling lines leading to a central tritium analyzer. These may be available for sampling. Alternatively, bag samples may be taken from individual rooms.
(b) Compatibility of proposed tests with pressurization tests presently used	
- off-power, medium (2 psig) or design pressure test	Limited time (5 h) available for tracer gas test.
- quarterly on-power, low presure (1 to 2" H_2O(g)) test	The time the vault is at positive pressure is the time available for tracer test (1 h or less). Bag sampling is necessary.
- commissioning tests	Significantly more time available for tracer tests.
(c) Mixing of tracer gas within containment	Rapid mixing desirable such that (i) a uniform concentration is obtained and (ii) tracer can be introduced to the final desired concentration as soon as the final desired pressure is attained.
- vault area: air cooling units provide good mixing	
- FH duct, VB pressure relief duct, central service area: poor mixing expected	
(d) Areas adjacent to penetrations through containment	
- accessibility	Access to penetrations may be limited by height and equipment interference.
- ventilation flow and direction	Low but finite ventilation flow rates desirable to reduce tracer build up in large open areas adjacent to containment. The ventilation flow is seasonal. Portable tracer gas analyzer with quick response desirable. Ventilation system shut off is desirable in rooms adjacent to containment especially if penetrations exist. Portable fans in rooms desirable for accurate leak quantification.
(e) Process equipment isolation	
- vault dryers	Process equipment isolation will improve accuracy of tracer gas test and provide an evaluation of the isolation procedures, eg, testing of double block and bleed valves on vault dryers.
(f) Choice of tracer gas	
- effect of decomposition products on equipment and on personnel	Stability to radiation and to 300°C (feeder pipe temperature) in the presence of -18°C dew point water vapour and carbon steel is required.
- background concentration	Minimum in-station background desirable.

2.1.2 Pressurization Tests - Individual Room Monitoring

During pressurization tests, it is expected that the tracer gas concentration will increase in rooms adjacent to containment if leaks into these rooms exist. Monitoring of these rooms (Appendix C) should start just about ten minutes after completion of tracer injection since the mixing in the vault is very rapid. Because only a limited time is available for each leak test and the number of analytical instruments will be limited, bag sampling and later analysis is indicated. Each room adjacent to containment will be mixed with a portable fan prior to sample collection. The tracer concentration in the room will be determined at time t and at time $t + \Delta t$, where Δt is about 30 minutes. Knowing the tracer gas concentration near the wall on the containment side allows leak quantification in the sampled room. This assumes that instrument air in-leakage in the sampled room is small or can be estimated. A small error (5%) will be present if there are leaks of up to 200 L/min to the external atmosphere through the walls of these rooms or the door seals. In addition, the adsorption of tracer gas on concrete or paint in these rooms, although believed to be small, should be quantified to eliminate this uncertainty. It will be necessary to shut off the ventilation flow in these rooms and perhaps seal the inlet and outlet with plastic wrap and tape.

2.1.3 Pressurization Tests - Open Area Monitoring

Leak characterization in open areas adjacent to containment is discussed in Appendix D. Monitoring in open areas should commence about 10 minutes after tracer injection to avoid difficulties with an increase in background levels of the tracer gas. The ability to detect the presence of a tracer gas at some distance from a leak depends not only on the distance but also on the ratio of the concentration of the gas at the leak to the background concentration or to the lower detection limit of the analyser used. Much higher concentration ratios are possible with SF_6 compared to helium. Sampling must be carried out within two to three metres from the containment walls for SF_6 or within 0.5 to 0.9 metres if helium is used. Location of sites having leaks greater than about 20 L/min appears possible provided the ventilation flow rate is not significantly greater than one metre per second. At higher ventilation flow rates the tracer gas will be rapidly dispersed making leak site identification possible only at very short distances from the site. However, depending on air flow rates and direction, high SF_6 concentrations in a sector would indicate significant total leakage there.

Leak quantification may be possible with additional developmental work, but the unpredictability of turbulence factors suggests that accuracies better than 20% are unlikely.

2.2 Tracer Studies During Normal Station Operation

An alternative procedure for leak testing a portion of the containment wall during on-power operation has been considered. The procedure applies only to the boundary of containment which forms the walls of individual rooms. There are about 30 rooms for each unit but the coverage of the containment boundary area is estimated to be 25% or less. Nevertheless, the investigation of leakages in these rooms while on power does not have severe time restrictions. Also, it would reduce equipment and manpower requirements during the air pressurization tests.

Normally, the pressure in the rooms is above the containment pressure but below that of the atmosphere on the station side. The overall procedure involves reducing the pressure in several rooms to below the containment value, injecting SF_6 into containment and measuring the SF_6 concentration in the rooms after about one hour. Use of helium is not possible because of its presence in the atmosphere external to the room on the station side.

Room preparation consists of the following. Preliminary checks will be carried out to ensure there are no gross leaks from the external atmosphere to the room through seals, penetrations and cracks in the concrete. The ventilation inlet valve is closed and the ventilation outlet is covered with a supported plastic film through which the outlet of a hose passes. The inlet of this hose is attached to a positive displacement vacuum pump which is run until the pressure in the room falls to the desired value. About 30 minutes will be allowed to obtain a 500 Pa (= 2" H_2O) pressure decrease in a 130 m^3 room. This value must be below the containment pressure and will be below the pressure external to the room on the station side. An automatic control system with pressure recording capability will be activated to turn the pump on and off for pressure control. A timer will also be turned on and off allowing outflow to be determined by multiplying the running time by the pump capacity. Mixing in the room will be accomplished with a portable fan. Finally a timer will be set to activate an air pump about 60 to 80 minutes after tracer injection. The pump will run for about five minutes and deliver air samples into a gas sampling bag.

The bag samples will require later analysis by gas chromatography. Several rooms, for example, on the same level can be tested simultaneously. This depends on equipment availability (vacuum pumps, pressure control systems, sampling pumps with timers) and is subject to trouble free operation of the ventilation system for these rooms while they are under test.

The SF_6 concentration introduced into containment will be ten times lower than in the full scale air pressurization tests. About 1.5 kg of SF_6 will be injected at one unit only. Possible locations include a tritium sampling line or a duct in the fan room. A concentration of 10 µL/L will be obtained but diffusion in the fuelling machine duct will reduce this with time. Hence, the concentration on the containment side will have to be monitored close to the walls under consideration. Measurement with an IR analyser attached to suitable (tritium) sampling lines will be adequate.

Errors arising due to temperature changes and pressure changes will be small when compared to a typical room volume of 130 m^3 and can be corrected. For example, a one degree change in temperature will change the volume of the air in the room by 400 L (0.3% of the room volume) while the corresponding value of a 0.1" H_2O (25 Pa) pressure change is 30 L.

The required capacity of the vacuum pump will depend on the containment leakage rate, the leakage rate from the station side and the instrument air used in the room for control valves. It will be necessary to estimate air input into the room through control instrumentation or to measure it to determine the maximum rate of usage. The present indication is that about 70 L/min is required by each control valve.

3.0 CONCLUSIONS AND RECOMMENDATIONS

1. The use of a tracer gas during off-power pressurization tests will permit the identification of leak sites in large sectors of overall station containment, eg, individual units, north passages, reactor reactivity controls area, and different floors in each area.

2. During off-power pressurization tests, leaks which occur through containment into adjacent rooms may be quantified. Leaks greater than approximately 20 L/min to open areas may be located provided ventilation flows are not excessive but quantification of these leaks requires further development work.

3. Sulphur hexafluoride is the preferred tracer gas for off-power pressurization tests. Recommended in-vault concentrations are 100 μL/L if open area sampling is to be carried out or 10 μL/L if only closed room sampling is to be performed.

4. Tracer gas may also be used for leak site identification and quantification during on-power operation but it is only possible for containment boundaries which make up the wall(s) of adjacent rooms. The tracer gas recommended is sulphur hexafluoride at an in-vault concentration of 10 μL/L.

5. It is recommended that:

   (i) in-station trials be carried out to test the validity of the tracer gas technique during off-power pressurization tests;

   (ii) a preliminary test be carried out in-station to determine on-power leakage of the containment boundary adjacent to several rooms and the instrument air flows to these rooms;

   (iii) the background concentration of SF_6 in nuclear generating stations be confirmed to be <20 nL/L, ie, the lower detection limit of the portable infra-red analyzer;

   (iv) experimental studies on the adsorption and desorption of SF_6 on concrete, epoxy paint and molecular sieves and diffusion of helium through concrete and epoxy paint be carried out;

   (v) leak quantification in open areas be studied experimentally to determine the effect of ventilation flow rate and turbulence;

(vi) the use of fans in the fuelling machine duct be examined to determine their effectiveness in mixing of the tracer gas.

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APPENDIX A

TRACER GAS SELECTION

A.1 Selection Criteria

Three different gases were examined for use as a tracer. These were: helium, tritiated water vapor, and sulphur hexafluoride.

The criteria used for tracer gas selection were: (1) amount of tracer to be injected; (2) ratio of vault concentration to background level or lower detection limit of the tracer gas; (3) time for a single measurement; (4) adsorption of tracer gas on concrete, epoxy paint, and feeder cabinet insulation, and diffusion through concrete and epoxy; (5) presence of (leaky) equipment in which the tracer gas forms a part of the process stream or other gases which can interfere with the response if their concentration changes; (6) decomposition and formation of corrosive or toxic products in a radiation field; and (7) decomposition and formation of corrosive or toxic products at feeder pipe temperatures.

A.2 Tracer Gas Performance Relative to Selection Criteria

The evaluation of each tracer gas with respect to the selection criteria is summarized in Table A.1. Data was gathered for tritiated water vapour but the work was discontinued after the several disadvantages listed in Table 1 were identified.

For a full station containment test the quantity of SF_6 to be injected is small. However, a large quantity of helium is required to produce high concentrations relative to the background helium concentration. Samples of gas from Rooms 017 and 312 at Unit 6, Bruce NGS "B", were analyzed for helium content. Mass spectrometry and gas chromatography with an ultrasonic detector showed that the helium background was about 10 to 12 µL/L, ie, twice the usual value. The amount of helium required would be reduced if only a portion of the containment is tested.

Immediately adjacent to a leak the concentration of tracer gas in the escaping air is the same as that within containment. The measured concentration will decrease with increasing distance from the leak and increasing ventilation flow velocity until the background value is reached. In a preliminary laboratory study using an infra-red analyser the ratio of the concentration of SF_6 tracer gas "within the vault" to the lower detection limit was 100µL/L ÷ 20 nL/L = 5000. At a distance of only 0.5 m and a ventilation flow of 1 m/s, this ratio had already decreased to 25, that is 200 times less than the original value. At a distance of 4 metres the ratio of the measured tracer gas concentration to the lower detection limit was unity. Therefore, all measurements for SF_6 using an infra-red analyser would have to be made closer than this distance.

With respect to helium at a containment concentration of 3000 µL/L, the initial value of this ratio using a thermal conductivity detector is only 200. This small dilution available suggests that detection will be limited to distances less than about 0.5 m from a leak. However, since the background concentration of helium is approximately 10 µL/L the total helium concentration at 0.5 m will

TABLE A.1

TRACER GAS CHARACTERISTICS

Tracer	Containment Concentration Expected*	Tracer Volume Injected	Background Level (BG)	Method of Analysis	Practical Lower Detection Limit (LDL)	Ratio of Vault Concentration to BG or LDL	Comments
SF_6	10^5 nL/L (=100 µL/L)	9500 L 60 kg	10^{-3} nL/L rural; estimated 0.5 nL/L in-station	Infra-Red Adsorption	20 nL/L	5000 (LDL)	Each determination 1-2 minutes; portable analyser.
				Electron Capture Gas Chromato-graphy	<0.003 nL/L	200,000 (BG)	Bag sampling required; slow, once per 6 minutes excluding transportation time; oxygen removal complicates equipment and procedure;
				SF_6 Leak Detector Ion Track Model 61	100 nL/L	1000 (LDL)	HTO interference possible; hand-held unit; response time about 30 seconds.
							Gas cost $1,500; for effects of radiation and temperature see text, A.2; Adsorption by insulation cabinet (if cold), concrete; epoxy unknown.
He	3000 µL/L	300,000 L 50 size IA cylinders required for total station test	5 µL/L normally in air; preliminary measurement in-station 10 µL/L	Thermal Conductivity Leak Detector	15 µL/L	200 (LDL)	Each measurement 30 secs; probing within 0.5 m of leak site necessary; hand-held, portable unit.
				Gas Chromatograph	<15 µL/L	300 (BG)	Slow; bag sampling required.
				Mass Spectrometer SX200	2 µL/L	300 (BG)	Each measurement 60 sec; bag sampling required for existing unit; portable units available for 20 K$; interference by HT negligible but D_2 will be problematic if concentration is high.
							Containment gas concentration limited to maintain 20% O_2; gas cost $4,000; background may be higher in rooms containing equipment in which helium is present. Leakage during test will reduce accuracy. Low adsorption of gas expected.
Tritiated Water Vapor	100 MPCa	None Injected	Variable over a wide range (0.1 MPCa to over 100 MPCa)	Proportional Counter	0.1 nCi/L	<1 to 1000 (BG)	Response time, 2 min but memory effects can increase time if concentrations are high.
				Ionization Chamber	2 nCi/L	<1 to 500 (BG)	
				Bubblers	<1 nCi/L	<1 to 1000 (BG)	Cheap, compensation not required, concentration results not available for several hours.
							DTO present may be due to equipment leaks in room and not containment leakage. Noble gases may interfere with results.

* Poorly mixed areas may have lower concentrations.

be greater than the lower detection limit. A more accurate analysis requires the ratio $(C-C_{BG}/C_{vault}-C_{BG})$* to be conserved with distance for different tracer gases with different background levels. It indicates that at the lower detection limit of 15 μL/L and background concentration of 10 μL/L, the concentration ratio is 600. This concentration ratio was obtained in the preliminary work with SF_6 at about 0.9 m from the leak site. Therefore all measurements for helium using a portable detector would have to be made closer than this distance. This will not be possible without the use of scaffolding.

For either SF_6 or helium, concentration measurements will be available either within a short time period (approximately 0.5 - 2 minutes for the portable analysers) or after about 10 to 15 minutes with bag sampling. For open area monitoring (as opposed to monitoring in rooms adjacent to containment) use of portable analysers is the only practical approach. Furthermore, a high concentration of tracer gas in containment is necessary. This is because (i) the lower detection limits of the portable analysers are large, and (ii) the tracer gas concentration decays rapidly with distance from a leak site.

The adsorption of helium on concrete or epoxy is not expected to be significant at room temperature. The indications are that it will permeate through concrete at a greater rate than does air but the magnitude is not known at present. Further work is recommended. Similarly, information on the adsorption and diffusion of SF_6 tracer gas through concrete and epoxy is not adequate, at present. As discussed below, the adsorption is expected to be small, however additional work is recommended. In Table A.2, a low score was therefore awarded to SF_6 in this category although its performance may be significantly better. The measurement accuracy with helium as the tracer gas is also affected by the presence of leaky equipment in which helium is part of the process stream.

Some decomposition of SF_6 will occur in the radiation field and at high temperatures in the presence of water vapour and metal surfaces. Sufficiently high temperatures (approximately 300°C) will exist at the feeder pipes upon reactor start-up. Similar temperatures also exist at the heaters in the regeneration circuit of the molecular sieve dryers used for D_2O vapour recovery. The breakdown products are toxic and corrosive. In the presence of water and air, they are SF_4, S_2F_{10}, SO_2F_2, SOF_2 and HF. Personnel exposure is not expected to be significant since access is limited and protective gear may be worn. However, corrosive attack is possible.

The amount of SF_6 breakdown is expected to increase with increasing time at the elevated temperatures and in the radiation fields. The minimum residence time in the station is determined by the flow out of the four exhaust dryers. For a 95,000 m^3 containment volume and a total exhaust flow of 70 m^3/min, one volume change will occur in about 24 hours. Under these conditions, the SF_6 will be essentially purged from the system after about three volume changes or about 70 hours if no adsorption occurs. In reality, the SF_6 residence time in the station will be longer. This is due to adsorption on the charcoal filters and the molecular sieves in the containment D_2O recovery system. This adsorption is inconvenient not only because the SF_6 residence time in the reactor area is increased but also because decomposition can occur at the regeneration heaters.

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*C_{BG} = background concentration

The effect of the above adsorption cannot be estimated exactly but is expected to be small. A laboratory test of SF_6 adsorption (1 μL/L in air) on a 5 cm long charcoal bed at a 0.2 m/s face velocity showed only a weak adsorption since breakthrough was obtained in minutes. The adsorption of SF_6 on molecular sieve is also expected to be small. This is because SF_6 is non-polar and strong electrical charges resulting in attractive forces are not present. Also, the molecular diameter of SF_6 is relatively large (approximately 5.5 Å diameter) compared to the effective pore diameter/5/ (approximately 8.5 Å) of type 13X molecular sieve. Finally, preferential adsorption of water will occur and this will displace any SF_6 adsorbed. It is recommended that after any tracer gas test using SF_6 the condensate obtained during regeneration be monitored for fluoride content to confirm the above. It is also recommended that the containment be as dry as possible before leak testing so that the dryers can be run as long as possible to purge SF_6 before regeneration is required.

Data from Allied Chemical indicate that exposure of pure SF_6 in a cylinder for 200 hours in a field of 10^6 rads/h of Cobalt-60 would result in the hydrolyzable fluorides increasing to about 140 μL/L. This information suggests that about 0.01% of the SF_6 would be decomposed in the radiation field. This is equivalent to about 8 g of SF_6 decomposing and reacting with only 3 grams of iron to form FeF_2.

The decomposition rate of SF_6 at the temperature of interest (300°C) in the presence of water vapour of dew point -18°C (approximately 100 μL/L H_2O) was investigated experimentally. A 1.9 cm diameter carbon steel pipe attached to a one litre container was used to simulate the feeder pipe surface area to containment volume ratio. A steady decrease of the SF_6 concentration to 75% of its initial value (approximately 100 μL/L) was observed after 45 hours. After this time the SF_6 concentration remained constant for 220 hours. If all the SF_6 which had decomposed (25% of 60 kg) reacted with metal, about 6 kg of iron would be converted. For 3840 feeder pipes in the station, this would be equivalent to an average depth of attack of 0.1 μm. This is significantly less than is removed in cleaning processes/6/. Hence, several tests may be carried out over the lifetime of the plant.

A.3 Scoring Tracer Gas Performance

Scores assigned to each tracer gas by the author are shown in Table A.2. The numbers do not have the accuracy for a definitive choice of the gas to be selected. However, they do show that sulphur hexafluoride and helium are promising candidates. Low scores were deliberately assigned to SF_6 on the areas of accuracy and hazards. Additional experimental work may show that SF_6 is significantly superior to helium.

TABLE A.2

ESTABLISHING PROMISING TRACER GAS THROUGH SELECTION CRITERIA

Criterion		Weight	Tracer Gas SF_6 Score	Tracer Gas He Score	Tracer Gas HTO Score
1. Dilution available	Ease of Measurement	10	10	0	0
2. Measurement time	Ease of Measurement	10	7	9	0
3. Potential for adsorption/diffusion	Accuracy	10	4	7	4
4. Potential for interference	Accuracy	10	10	5	0
5. Radiation stability	Hazards	10	8	10	10
6. Temperature stability	Hazards	10	0	10	10
7. Injection amount	Hazards	5	5	0	5
		65	44	41	29

APPENDIX B

PRESSURIZATION TESTS
TRACER GAS INJECTION AND MIXING

Tracer gas may be injected through any line used to add instrument air to pressurize the containment. However, injection through the tritium sampling lines (or any similar lines such as at the air cooling fans) is preferred. This allows a more uniform tracer concentration throughout containment in a shorter time because several injection points are available. One or more of the four lines in each vault and two of the four in the central services area can be used. Valves and suitable fittings will be required to isolate those lines from the tritium monitors. About 25% of the tracer gas will be injected at Unit 1, about 15% each at Unit 2, the central fuelling area and Unit 3 and another 25% at Unit 4. This allows for the different volumes of gas in each area. The assumed volumes of each reactor vault, the central fuelling area, the east services area, the fuel duct, and the pressure relief duct are 12,000 m^3, 14,000 m^3, 4,500 m^3, 20,000 m^3 and 12,000 m^3, respectively.

For an average pseudo steady-state SF_6 tracer gas concentration of 100 $\mu L/L$ (see Appendix D) when the constant pressure period is reached, about 9,500 L (approximately 2m x 2m x 2m) of gas must be metered into the 95,000 m^3 containment volume. Injection of tracer gas will commence 20 minutes before the constant pressure period is reached or the air cooling units and fans are switched off as discussed below. This will minimize the increase in background levels prior to quantitative leak rate measurement. Ten minutes will be allowed for injection and a further ten for mixing. At each injection point, the maximum injection rate of about 200 L/min is expected to be achievable with mass flow meters. However, it may be necessary to have two or three SF_6 cylinders connected in parallel to avoid excessive cooling of the delivery apparatus. Assuming low instrument air in-leakage into containment and a containment leakage rate of 16,000 L/min (1% of containment volume) at low pressure, it will not be necessary to add tracer gas to maintain a constant tracer gas concentration. For an eight hour constant pressure period, the tracer gas concentration should fall by only about 1%. No fall is expected during pressure decay tests.

Mixing in each vault (Room 206) is expected to be rapid. This is because the volume of the vault is about 12,000 m^3 while the air cooling units and main fans move about 12,000 m^3 per minute. Mixing in the area of the fuelling machine duct immediately below the calandria is also expected to be adequate because the fans direct about 1,700 m^3/min into this area. However, it is understood that the motors on the fans and air cooling units become overloaded at pressures above 2 psig and mixing will likely be poor above this pressure. Individual leak rates determined above 2 psig would be of reduced accuracy unless tracer gas concentrations in each of the four vaults are intermittently monitored. The volumes of the central fuelling area, the east services area, fuelling machine duct and the pressure relief duct are given above. Mixing in these areas is expected to be poor. It may be possible to mount fans on the fuel transportation trolleys which can then move along the fuelling machine duct to the east services area and the pressure relief duct area.

APPENDIX C

PRESSURIZATION TESTS
TRACER GAS SAMPLING IN ROOMS ADJACENT TO CONTAINMENT

Containment leakage into adjacent rooms will be indicated by a significant rise in the tracer gas concentration in these rooms. It will be necessary to shut off the ventilation flow which also allows pressure equalization between the room and the station atmosphere and only low leakage from the room to the station atmosphere. For a typical room of size 4m x 8m x 4m, the rise in tracer gas concentration per 30 minutes will be about 500 nL/L (0.5 µL/L) neglecting for the moment instrument air in-leakage and leakage to the station. This calculation also assumes a 20 L/min leak and an SF_6 gas concentration in containment of 100 µL/L. This rise in concentration is easily measurable even with a portable IR analyser but several analysers would be required to measure the large number of rooms if only a short time is available. It is considerably larger than the background SF_6 concentration which is estimated at 0.5 nL/L. This latter concentration has been observed in buildings adjacent to SF_6 switchgear areas and in which SF_6 is normally used.

The above SF_6 concentration introduced into containment can be reduced by a factor of ten if monitoring in open areas which requires a large concentration ratio is not required in conjunction with room sampling. In this case, the SF_6 concentration will increase by 50 nL/L in 30 minutes in a 4m x 8m x 4m room with a 20 L/min containment leak. A gas chromatograph will be required for analysis because of the low concentration of the tracer gas. Also, bag sampling would allow a large number of rooms to be investigated in a relatively short period.

For helium, the rise in tracer gas concentration per 30 minutes will be about 15 µL/L. This assumes a 20 L/min leak of 3000µL/L gas into the 4m x 8m x 4m room.

The above analysis assumes negligible instrument air in-leakage. The present indication is that instrument air use per control valve is 70 L/min so the volume input per 30 minutes would be 10,500 L if there are five control valves in a room. This is about 10% of the room volume and will result in a 10% error in the SF_6 concentration measured and therefore in the containment leakage rate if not taken into account. An additional error will be present if there are leaks to the external atmosphere on the station side through the walls of these rooms or the door seals. However, these will have only a small (5%) effect on the accuracy of the results for a well mixed room provided the external leak is less than about 200 L/min. This rate appears unlikely at the low differential pressure between the room and the external atmosphere. Small changes in room temperature (approximately 3°C) and pressure (approximately 1000 Pa) should not affect the results significantly. Humidity changes are also expected to be negligible. However, as previously noted, the adsorption of SF_6 on concrete or paint requires further investigation.

A preliminary list of possible rooms to be sampled and a description of the penetrations believed to exist at present are given in Tables C.1 and C.2.

It is assumed the air locks and transfer chambers can be individually tested on-power with or without tracer gas. There are, therefore, about thirty rooms per unit which are adjacent to the containment and can be tested. Penetrations from containment have been identified for about fifteen of these. At least one room, ie, the poison injection room (R224) which has no door will require a plastic sheet taped to its entrance for adequate isolation.

Collection of the first of fifteen samples for each reactor building will commence about ten minutes after the end of the injection period. Two crews will be required for each reactor building making a total of eight oil free vacuum pumps necessary. Assuming eight minutes for each sample would allow completion of sample collection one and one-half hours from the end of the pressurization period. For a total of sixty rooms in the station, the number of sample bags (approximately two litres each) required is one hundred and twenty. Analytical time at five minutes per sample would be at least ten hours.

TABLE C.1

ROOMS ENCLOSING PENETRATIONS TO OR ADJACENT TO CONTAINMENT
IN VAULT AREA FOR EACH OF FOUR UNITS
(PRELIMINARY INFORMATION)

Room Number	Elevation (feet)	Name of Room	Description of Penetration	Tritium Sampling Lines Present	Comments
R004	579	Moderator System Auxiliary Room	1 pipe sleeve for moderator	yes	R refers to reactor building
R005	579	D_2O Collection Area	1 tube nest for moderator instrumentation		
R006/007	579	Moderator HX, E&W	1 pipe sleeve for moderator/1 pipe sleeve		
R010	579	Fan Room	4 sleeves in vault atmosphere, 4 ventilation ducts		
R011	579	Transfer Chamber 5	Door frame, 4 sleeves for electric cables, 20 locking devices gaskets, O-rings, pressure fittings, adapters, breathing air supplies, 16 gaskets and O-rings		Individual on power leak testing possible with or without tracer gas
R012	579	Fan Room Emergency Exit, Air Lock 6		yes	
R017/R018	579	D_2O Collection/ Sampling Room		yes	
R014	591	Moderator Pump Room, East	1 pipe sleeve 12", 1 pipe sleeve 8"	yes	
R105	591	Moderator Pump Room, West	1 pipe sleeve 12", 1 pipe sleeve 8"	yes	
R106	591	Moderator HX Room, East	1 pipe sleeve 10"	yes	
R107	591	Moderator HX Room, West	1 pipe sleeve 10"	yes	
Airlock 2	615		Expected similar to R011		Individual testing possible
Airlock 3	615		Expected similar to R011		
R202	615	Heat Transfer System Aux Room	3 sleeves for electrical cables		
R203	615	Moderator System Aux Room	1 sleeve for electrical cables		
R210	615	Process Instrument Room			
R223	615	Poison Mixing Room		yes	Sampling line for R223 located in R207 (north passage)
R224	615	Poison Injection Room			
R305	629	Activity Monitoring Room, East	1 square sleeve for tubing, 1 sleeve for activity monitoring		
R306	629	Activity Monitoring Room, West	1 square sleeve for tubing, 1 sleeve for activity monitoring, 2 sleeves for instrument flow monitoring		
Airlock 4	639		Expected similar to R011		
Airlock 5	639		Expected similar to R011		
R302	639	Heat Transport System Auxiliary			
R303	639	Moderator System Auxiliary Room			

Room Number	Elevation (feet)	Name of Room	Description of Penetration	Tritium Sampling Lines Present	Comments
R304	639	Maintenance Cooling Piping Room			
R310	639	Heat Transport Monitor			
R311	639	Instrument Room East	Approximately 6 square sleeves for tubing		
R312	639	Instrument Room West	Approximately 6 square sleeves for tubing		
R313	639	Radiation Monitoring Instrumentation West			Sample line for reactor vault (R206) in this room
R318	639	Shower			
R404	663	Reactivity Control Area	4 frames for main circulation pumps, 1 frame for reactor top shield tank		
R408	663	Boiler Room East	4 frames for boilers, 2 frames for preheaters, 16 sleeves for support rods		
R409	663	Boiler Room West	4 frames for boilers, 2 frames for preheaters, 16 sleeves for support rods		

TABLE C.2

ROOMS ADJACENT TO CONTAINMENT IN CENTRAL SERVICE AND FUELLING MACHINE DUCT AREA

Room Number	Elevation	Name of Room	Description of Penetrations	Tritium Sampling Lines Present	Comments
A111	579	Air Locks - Fuelling Machine Duct			All can be individually tested
AL12					
AL15				yes	
AL16					
S235	615	Transfer Chamber 1			
		Central Service Area		yes	
S237		Transfer Chamber 2		yes	
S239		Transfer Chamber 3		yes	
S241		Transfer Chamber 4			

APPENDIX D

LEAK CHARACTERIZATION IN OPEN AREAS

D.1 Leak Site Identification

Monitoring in open areas adjacent to containment requires the use of a portable analyzer, eg, an infrared analyzer, with a rapid response time. Hence relatively higher SF_6 concentrations are required as compared to concentrations measurable with a gas chromatograph. Leak site identification should be possible/4/. This assumes a 20 L/min leak, a 100 µL/L SF_6 concentration in containment, sample collection about two to three metres from the leak site and a ventilation flow in the area which is less than 1 m/s. It may be possible to turn off the fans feeding the non-contaminated stack if the ventilation velocity exceeds 1 m/s. Sampling will be concentrated near to containment walls. Very small smoke sticks or cigarette smoke must be used to rapidly indicate the position at which the first sampling should be done. Sampling will proceed perpendicular to the direction of the gross ventilation flow until the position of the peak concentration is identified. Additional sampling will then be done along the ventilation flow direction from downstream to upstream. The ability to access areas as high as 10 m from floor level is required.

D.2 Leak Quantification

Approximate leak quantification for sectors requires velocity and concentration determinations at selected points for a mass balance to be possible. Individual site leak quantification is more difficult and will require additional development work. Two methods have been considered. The first is based on correlation of open air concentration measurement with several factors including leak rate. Preliminary information has previously been reported/4/. For a given distance from a leak (0.5 m) and with SF_6 concentrations at the leak site above about 20 µL/L, a significant dependence of the SF_6 concentration with leak rate was observed. The second method is based on initial identification of a leak site followed by envelopment and measurement of flow rate out of the enclosed space.

D.2.1 Leak Rate Determination Through Open Air Concentration Measurement

The concentration measured will be a function of (1) the physical size of the leak site, (2) the velocity through the leak site, (3) the distance from the leak site, (4) the magnitude of the ventilation flow at the sampled location, (5) the intensity of turbulence at the sampled location, and (6) the sampling duration.

Gaussian concentration distributions are normally assumed in atmospheric tracer tests covering less than about 15 km. A similar analysis indicates that for a leak of small dimensions (approximately 0.05 m) from a wall, the concentration at a distance x from the leak is given by:

$$\frac{\text{Tracer gas concentration - Background concentration}}{\text{Containment concentration - Background concentration}} =$$

$$\frac{\text{Leak Rate}}{\text{Ventilation Velocity}} \frac{1}{\Pi\sigma_y\sigma_z} \left[\exp \frac{-y^2}{2\sigma_y^2}\right]\left[\exp \frac{z^2}{2\sigma_z^2}\right] \qquad \text{(D.1)}$$

where x = distance along the center of the plume from the leak point

z = distance perpendicular from containment wall

y = lateral distance from center of the plume

= standard deviation of plume concentration distribution in the x,y plane; σ_y is a function of x

= standard deviation of plume concentration distribution in the x,z plane; σ_z is a function of x

Consider the case where the leak origin has been determined and concentrations are measured along the plume center line, ie, y = 0 and z = 0. From equation (D.1)

$$\text{Dimensionless concentration at a given x} = \frac{\text{Leak rate}}{\text{Ventilation velocity } (\Pi\sigma_y\sigma_z)}$$

The tracer gas concentration will be a function of the leak rate, the ventilation velocity and the standard deviation terms. High concentrations will be obtained with high leak rates, low ventilation velocities and low intensities of turbulence. However, the ventilation velocity should not be too low. Low velocities will result in buildup of tracer gas concentrations in the area with time. Also, response times will be long since sampling should be carried out isokinetically. Scouting tests in the laboratory on the correlation of the $(\Pi\sigma_y\sigma_z)$ term with turbulence intensity and sampling time are recommended. It is likely that the accuracy of this method will be limited. Its greatest value will be in the identification of major leak sites which would require maintenance work.

D.2.2 Leak Envelopment and Measurement

This method is applicable in a practical situation to those leaks only over which a rigid, foam-sealed box can be placed. For example, leaks along straight caulked seams can be monitored. Hence, leaks around nests of tubing cannot be quantified unless rapid envelopment with an adequately rigid enclosure is possible. Assuming leaks of 5 L/min up to about 1000 L/min, simple velocity monitoring would be sufficient for leak quantification. A hot wire anemometer can be used to measure the velocity at the center of a short length of pipe equipped with flow straightening vanes. Lower volume flow rates (<5 L/min) can be easily measured with calibrated glass measuring burettes utilizing soap films for flow rate

indication. However, it is unlikely that one would be interested in quantifying such small leaks.

This method suffers the disadvantages of being extremely labor intensive and slow. Also, the leak site must be accessible. Its practical value is probably that large leaks may be accurately quantified so as to compare the overall leak rate with the sum of the individual determinations.